Physics and engineering of nuclear reactors at the ”Ecole Nationale Supérieure de Physique de Grenoble” of the ”Institut National Polytechnique de Grenoble”

E. Merle-Lucotte, R. Brissot

PHYSICS AND ENGINEERING OF NUCLEAR REACTORS AT THE *ECOLE NATIONALE SUPÉRIEURE DE PHYSIQUE DE GRENOBLE* OF THE *INSTITUT NATIONAL POLYTECHNIQUE DE GRENOBLE*

E. MERLE-LUCOTTE, R. BRISSOT
ENSPG-INPG/LPSC-CNRS
53, avenue des Martyrs, F-38026 Grenoble Cedex - France

ABSTRACT

If the use of fossil fuels is to be limited to curtail greenhouse gas emissions, fission nuclear energy is, along with new renewable energies, one of the primary energy sources able to respond significantly to the increasing worldwide demand. In this context, it is necessary to design and evaluate new generations of nuclear reactors as defined by the Gen IV International Forum. The Energy and Nuclear Engineering (GEN) curriculum of the *Ecole Nationale Supérieure de Physique de Grenoble* (ENSPG), one of the nine engineering schools of the Grenoble Institute of Technology (INPG), includes a balanced blend of basic courses in energy, nuclear and thermal hydraulic engineering, together with the corresponding engineering sciences to cover the technological aspects. The objective is to train engineers who shall master not only nuclear engineering for the production of electricity but, more broadly, energy and nuclear technologies and their various application fields.

1. Introduction

Nuclear reactors currently generate nearly one fourth of the electricity in the world, and nuclear technologies have spread into many other industrial areas: instrumentation, medicine, the food-processing industry, materials, etc. The worldwide demand for primary energy is increasing; solutions have to be sought and the level to which these solutions are adapted to the stakes have to be examined. Not many options are available if use of fossil fuels is to be limited to curtail greenhouse gas emissions. Fission nuclear energy is, along with new renewable energies and, in the longer term, fusion energy, one of the primary energy sources able to respond significantly to the demand [1]. In this context, it is necessary:

- To ensure transfer of competences between generations
- To design and evaluate new types of nuclear reactors as defined by the Gen IV International Forum [2]

Such research and development rests on a solid knowledge in physics, on technical innovations, and on efficient numerical and modeling tools allowing the management of these complex systems. The Energy and Nuclear Engineering (GEN) curriculum is one of the six specialty options of *Ecole Nationale Supérieure de Physique de Grenoble* (ENSPG), one of the nine engineering schools of the *Institut National Polytechnique de Grenoble* (INPG).

In this paper, after a brief presentation of the *Institut National Polytechnique de Grenoble* or Grenoble Institute of Technology (INPG), we will introduce the ENSPG. We will then detail the Energy and Nuclear Engineering curriculum, the most complete in France for engineers in the nuclear field. More precisely, three curricula are offered by ENSPG in the nuclear field: the Energy and Nuclear Engineering curriculum itself, a specialized training module in safety and risk management, and a research Masters' in the Physics of Energetics.

2. Grenoble Institute of Technology (INPG)

The Grenoble Institute of Technology (INPG) is one of four universities in Grenoble. The Engineering Schools of the Grenoble Institute of Technology train engineers in key industrial domains. Students are admitted two years after their high school graduation via a competitive entrance exam to the *Grandes Ecoles*, via University degrees, or an in-house Preparatory Course at Grenoble, Nancy and Toulouse Institutes of Technology. They can go on to do a Research Masters' Program and later a PhD, in one of 10 Masters' Programs and 8 Doctoral Schools.

Students graduate after three years of studies in one of the nine "*Grandes Ecoles*" or engineering schools which make up INPG:

- *Physique fondamentale et appliquée, et génie nucléaire* / Fundamental and Applied Physics and Nuclear Engineering (ENSPG)
- *Électronique et technologies de l'information* / Electronics and Information Technologies (ENSERG)
- *Energie et traitement de l'information* / Energy and Information Processing (ENSIEG)
- *Fluides, mécanique et environnement* / Fluids, Mechanics and Environment (ENSHMG)
- *Génie industriel* / Industrial Engineering (ENSGI)
- *Industries papetières et graphiques* / Papermaking and Printing Industries (EFPG)
- *Informatique et mathématiques appliqués* / Information Technologies and Applied Mathematics (ENSIMAG)
- *Matériaux, électrochimie, génie des procédés /* Materials, Electrochemistry, Process Engineering (ENSEEG)
- *Systèmes industriels embarqués* / Embedded Industrial Systems (ESISAR)

INPG is characterized by the following key figures:

- 5,200 students of which 20 % are foreigners
- 11 Engineering Degree Courses from which 1,150 engineers graduate every year
- 1 Masters' and Doctorate School College from which 180 PhDs graduate every year
- 40,000 alumni working worldwide
- 1 Professional Development Department
- 38 laboratories among which 3 are of international standard
- 1 private subsidiary for industrial valorisation, INPG Enterprise SA
- 1,100 teaching and research fellows
- 114 million euros budget

Several aspects of the organization or operation of INPG may appear exotic to a non-French reader. The engineering schools making up the INPG are actually "*Grandes Ecoles*". As for all French "*Grandes Ecoles*", where most of France's top leaders are trained, each school is characterised by a rather small size (under 400 students at ENSPG), and a very selective admission procedure. Students normally are admitted to a school after a competitive examination (*Concours d'Entrée*) which takes place after two years of intensive university-level studies. It is therefore essential to remember that the three years of studies at our engineering schools correspond to the third, fourth and fifth year of university (*post-baccalauréat*) studies.

We will now concentrate on the school of 'Fundamental and Applied Physics and Nuclear Engineering' or ENSPG.

3. Ecole Nationale Supérieure de Physique de Grenoble (ENSPG)

ENSPG stands for *Ecole Nationale Supérieure de Physique de Grenoble*, in other words Grenoble's Engineering School for Physics. ENSPG trains engineers and research physicists who master the various technologies originating from physics, and can make them evolve. It works at developing the students' creativity, and the human qualities they will need as leaders. Over 130 students graduate each year.

More so than other engineering schools, because of its topics and its environment, ENSPG is also strongly involved in graduate studies, leading to the PhD (*Doctorat*), normally obtained after three years of research work, with some courses, following completion of a research masters' degree.

Foreign students are of course welcome at ENSPG. These students can graduate from ENSPG under one of two conditions:

- If these students come from one of the universities with which ENSPG has a double-degree agreement (at the time being: Universität Karlsruhe and Politecnico di Torino), and choose, with their supervisor's agreement, to take the double degree scheme. These students will then obtain both their home University's and INPG's degrees.
- By applying for admission as a regular student at either of the two stages where it can be done: for admission into first year (normally after a 2-year or 3-year university curriculum), or for admission into second year (after a 4-year university curriculum). Admissions are decided on the basis of the student's records.

3.1 Organisation of the Education at ENSPG

The school's main objective is to train physics engineers with both a sound basic training in physics and competence in engineering sciences, economics and social sciences, mastering several foreign languages. The common-core syllabus, corresponding to the three first semesters, aims at this general education. More specialised training, corresponding to one of six specialty options, is given in the following three semesters of the three years of studies at ENSPG.

3.1.1 The common-core curriculum

The common-core syllabus covers the first three semesters or 1325 hours. They include personal work in the form of projects, and cover three main objectives:

- Basic education in the School's general specialty, the properties of matter and their theoretical models, with mathematics as a tool, during 450 hours (34% of the curriculum). Physics of matter is dealt with through lectures in basic physics (quantum and statistical physics, optics, solid state physics, semiconductors and thermodynamics, nuclear physics) and in material sciences (magnetic properties, crystallography, and physics of materials). This academic training is completed by an experimental approach thanks to practical work and a first year group project.
- Sound notions of basic engineering sciences (electronics, automatic control, signal processing, mechanical design, computer science, mathematics and numerical methods) covering 550 hours (41%), aimed at facilitating interdisciplinary exchange with specialists of other fields.
- Throughout the three years, 25% of the time (around 325 hours) is devoted to languages (English and a second foreign language), economics and management, to an introduction to geopolitics, and to sport.

3.1.2 Specialty training: the six specialty options

The student chooses one of the six specialty options. They cover two semesters of courses, followed by the final project. These curricula provide specialised training in areas chosen on the basis of existing or future industrial possibilities, and of Grenoble's technical and scientific environment. The six specialty options (in decreasing number of students) offered by ENSPG are:

- **"Energy and nuclear engineering"** (or 'GEN' standing for Génie Energétique et Nucléaire in French) covers the various aspects of energetics with a particular accent on nuclear technologies.
- **"Functional materials and nanophysics"** deals with materials with magnetic, superconducting, semiconducting... properties, and their applications, especially at the nanoscopic level.
- **"Physical instrumentation"** centres on the design and the technologies of instrumental devices.
- **"Instrumentation for biotechnologies"** centres on the physical and biological processes involved in the instrumentation used in life sciences.
- **"Structural materials"** centres on the preparation and modelling of materials with emphasis on their mechanical properties.
- **"Physics of electronic and opto-electronic devices"** covers microelectronics, optics, optoelectronics and associated technologies.

In section 4, we will focus on the first option, the "Energy and nuclear engineering" or GEN curriculum.

3.1.3 The third year: Special training modules and research masters

The third, final year at ENSPG (fifth year of university studies) is devoted to developing competence in the specialisation field chosen. It includes considerable flexibility, and can to a large extent be tuned to the student's plans for the beginning of his or her professional career. Thus, the courses in the third year include, apart from a kernel specific to each specialty option, a large choice of "specialised complements" which allow in-depth study of a discipline, or an opening to other fields. Two main options are offered.

1. students intending to complement their training through a PhD will normally follow, in parallel with their final year, a research masters' (graduate course) as a prerequisite for doctoral work. The research masters' associated to the nuclear specialty option and chosen by around 30% of the nuclear students is the Masters' in the Physics of Energetics described in section 4.3.
2. Students can also choose one of two modules: "Project Management and Quality" or "Safety Engineering and Risk Management" to complement their last year of studies. The module "Project management and quality" gives the students some training for jobs like product engineer, project engineer, business engineer, quality engineer. The aim of the module "Safety engineering and risk management" is to give engineering students some basic knowledge in the field of safety (nuclear or chemical safety). This becomes mandatory in positions involving responsibilities as department or laboratory manager. This INPG teaching module, directly linked to the GEN option, will be detailed in section 4.2.

An additional module concerning "Accelerator Physics and Technologies", an international course organized with a strong participation from the European Particle Physics Center, CERN, is open to students coming either from the nuclear engineering option or from the instrumentation option. As this training module leads mainly to PhD theses, students are encouraged to follow it though a research masters' like the Masters' in the Physics of Energetics described in section 4.3.

3.1.4 The training periods

After the first year, students can take a summer job in a company or a research laboratory, allowing them to discover their future work environment. At the end of the second year, students have to perform an internship of at least two months, normally in industry in France or internationally. At the end of the third and last year of studies, they have to complete a six month final project, involving an actual engineering or research work.
The second year internship and the final project lead to written reports and oral presentations.

3.2 Business Opportunities

From 1989 to 2001, ENSPG has awarded more than 1800 degrees. 60% of graduating students decided to begin their professional career straight away. The others preferred to add to the training received in the school either a doctorate (30% of the graduates) or another specialisation (5% of the engineers chose another scientific speciality, very often abroad; 5% chose to obtain a degree in economics or management).
The standard profile for an ENSPG alumnus a few years after graduation is a Research and Development job in a high technology field corresponding to the School's lines, either in Paris or in the Rhône-Alpes region. But there are many variations, ranging from Theoretical Physics to Marketing and Communication. In a survey of the jobs found after ENSPG by our engineering students, we found:

- 71% in the research and development field
- 13% as production, quality and security engineer
- 10 % in computing
- 6 % as business engineers and in marketing

The main field of opportunities for our engineers is the energetic area, and more precisely research and development in nuclear energy (34% of them), and also the area of 'physics and materials' and 'instrumentation' (23% each) and finally microelectronics and optoelectronics (20%).

4. Energy and Nuclear Education

4.1 The 'Energy and Nuclear Engineering' (GEN) Stream

Power production has been revolutionised for some thirty years by the increasing role played by nuclear energy, particularly in France where some 75% of the electricity is of nuclear origin. In the same way, nuclear technologies have spread into many other industrial areas: instrumentation, medicine, the food-processing industry, materials...

Nuclear energy cannot be separated from the energetic problems involved in the transportation of energy and in the transformation of heat into electricity. Therefore, energetics is also a huge application field.

Our objective is to train engineers who will master not only nuclear engineering for the production of electricity, but more broadly energy and nuclear technologies and their various application fields.

The curriculum "Energy and nuclear engineering" of ENSPG is original, and it is the only one in France that trains engineers in the nuclear field.

This one and a half year specialized training includes a balanced blend of basic courses in energy, nuclear and thermal hydraulic engineering, together with the corresponding technologies engineering sciences to cover the technological aspects. It is based on the solid background in physics acquired during the first year and a half of the common-core syllabus of our engineering school. The details of the courses are indicated in table 1.

SECOND YEAR COURSES: 340 hours	THIRD YEAR COURSES: 350 hours
Energy and Nuclear Physics: 175 hours - Advanced Nuclear Physics - Neutronics and Reactor Physics - Fluid Mechanics - Radiation-matter Interactions - Radiation Detection - Advanced quantum Physics	**Nuclear Engineering: 75 hours** - Reactor Kinetics - Nuclear fuel cycle and wastes management - Nuclear Metallurgy - Nuclear Reactor Simulations
Computing sciences: 20 hours	**Energy Engineering: 115 hours** - Thermal hydraulics - Thermal Radiation - Simulation in thermal hydraulics - Electrochemical conversion
Practicals: 80 hours - Physics Lab - Practice of numerical methods - Practice of computers in process measurement	**Practicals: 65 hours**
	Optional Lectures: 75 hours Among the lectures of the research master in Physics of Energetics, materials and foreign languages
Foreign Languages and Sports: 45 hours	**Foreign Languages: 20 hours**

Tab 1: Courses of the Energy and Nuclear Engineering Stream

Amongst the graduates, roughly 30% decide to add a PhD to the education received in the school, while 60% of them decide to launch their professional career straight after the 3-years education as engineers. Most of these join the design and invention department of major companies working in the field of nuclear power generation, like AREVA and EdF as far as France is concerned; a significant part of our alumni are working worldwide, mainly in nuclear industries. They carry out technical studies, develop calculation tools and methods, prepare next generation equipments, plants and technologies, or improve the performance of water reactors.

Another major field of employment, nuclear safety, is growing very fast: nuclear safety is of paramount importance and this requirement underpins the organization and operation of nuclear groups. As operating safety engineer, they ensure that safety and occupational safety criteria are met. They also work in radiation protection, radiological monitoring and risk assessment.

4.2 Safety Engineering and Risk Management

People are less willing to accept risks whether they are high scale risks (public safety related to nuclear, chemical or transportation activities) or more restricted risks (electrical failure, explosion...) or even natural risks. In his or her job, every engineer, as laboratory, section or firm manager, will have to take into account the existence of risks and will thus have to acquire some basic knowledge about safety.

The aim of the “Safety engineering and risk management” module is to give engineering students, as a complement to their specialty field, basic knowledge about safety. Various approaches are developed: risk analysis, concepts related to operating safety (failure trees...), structure reliability, risk identification and evaluation, regulation elements, insurance, crisis management… The course essentially concerns two fields of application: the nuclear and industrial chemistry risks.
This INPG module, though driven by ENSPG, also concerns two others engineering schools: the Materials, Electrochemistry, Process Engineering School (ENSEEG) and the Industrial Engineering School (ENSGI). The curriculum is thus organised so that students of all specialty options of the three engineering schools concerned can follow the whole module.

The 140 hours of lectures, delivered over seven weeks during the third year, deal with risk analysis methods (reliability diagrams, failure analysis, functional analysis, event trees, state diagrams, ergonomic approach), systems reliability, operation safety, technological risk, nuclear safety and radioprotection, risks of the industrial chemistry, impact of regulatory and insurance considerations, risk and crisis management…. These lectures are completed by practical studies on real cases during the last week of the module. Lectures are given mainly by industrial teachers from the French nuclear and chemical industries.

4.3 Master of Science Degree: Physics of Energetics

The Master Degree is the first stage of the doctoral study scheme. Students who complete a Masters’ Degree at the same time as their ENSPG engineer degree can thus directly embark on the preparation of a doctorate, which generally lasts three years. In France, the organisation of graduate studies is based on graduate schools (*Ecoles Doctorales*). *Université Joseph Fourier*, the Grenoble University of Science, operates the Graduate School in Physics in cooperation with INPG. Physics for Energetics is one of the specialties of this Graduate School in Physics, a specialty driven by INPG. More precisely, the specialty ‘Physics of Energetics’, a research oriented masters’ degree, is operated jointly with INSTN, the training subsidiary of the French Atomic Energy Commission, and with the Science University of Grenoble.

Each Graduate School runs a number of Masters’ Degrees, graduate courses which span a year but can be taken in parallel with the final year of ENSPG. They consist of a semester of courses, followed by four to six months of full-time research in an academic or industrial laboratory.
The first semester is organized in three different options, all three related by a physics approach:
- ‘Nuclear Energy’ option, corresponding to the research aspects of nuclear energy, enlarged by two lectures on energy to be chosen in the two other options of the master
- ‘Physics of Transfers’ option, covering the fields of thermal hydraulics, heat transfers and exchanges, two phase flow
- ‘Materials for Energy’ option, composed of lectures on solar energy, electrochemical conversion and energy storage (fuel cell), cryophysics, micro fluidics, physics of phase change

More detailed information can be found in reference [3].

Students from the Energy and Nuclear Engineering stream of ENSPG can prepare this Masters’ through a special training scheme including:
- a set of compulsory courses validated for the school and the masters’ (see list above)
- a set of specialized courses, specific to the school, in the continuity of the 4th semester

It leads to positions in the nuclear industry, in public or private research or development laboratories involved in energy problems, and in engineering companies.

5. Acknowledgments

We are very thankful to Ms. Elise Huffer for her help during the translation of this paper.

6. References

[1] E. Merle-Lucotte, D. Heuer, C. Le Brun, J.-M. Loiseaux, "***Scenarios for a Worldwide Deployment of Nuclear Power***", International Journal of Nuclear Governance, Economy and Ecology, Volume 1, Issue 2, pp 168-192 (2006)

[2] ***"A Technology Roadmap for Generation IV Nuclear Energy Systems"***, report GIF-002-00, http://gif.inel.gov/roadmap/pdfs/gen_iv_roadmap.pdf (2002)

[3] http://master-ep.inpg.fr (in French)